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Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures

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All at Sea
2013

4th-5th July
University of York

Organiser: Dr Katherine Selby

An integrated approach to research in the coastal zone

THE UNIVERSITY of York
Environment Department

INQUA
Commission on
Coastal and Marine Processes

IUGS UNESCO
Project 588

ECSA

Conference Programme

4th July

10.00-10.20 Arrival and Coffee

10.20-10.30 Welcome: Dr Katherine Selby

Nutrients and ecology of the coastal zone and how they improve our understanding of environmental change

Session chair: Dr Katherine Selby

10.30-11.20 **Keynote: Professor Mike Elliott** *Nutrients and ecology of the coastal zone – how good is our science and is it sufficient for environmental understanding and management?*

11.20-11.40 J. P. Lewis, D. B. Ryves, P.Rasmussen, K.L. Knudsen, K. S. Petersen, J. Olsen, T.J. Andersen and Kilen Project members, *Changing salinity and nutrient dynamics in the Limfjord, Jutland (Denmark) over long and short timescales*

11.40-12.00 N. Cosme, H. F. Larsen, M. Z. Hauschild, *Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures*

What challenges remain in understanding past and future sea-level variability?

Session chair: Dr Jason Kirby

12.00-12.50 **Keynote: Dr Ivan Haigh** *What challenges remain in understanding past and future sea-level variability?*

12.50-13.50 Lunch and poster viewing

13.50-14.10 S. L. Callard, A. J. Long, J. A. Cooper, D. Belknap, R. J. Edwards, J. Kelley, D. Long, X. Monteys, R. Plets, R. Quinn *Evidence of past glacial activity and relative sea-level change from the submerged landscape of Belfast Lough.*

14.10 – 14.30 M. H. Saher, W. R. Gehrels, N. L.M. Barlow, A. J. Long, M. Blaauw *Drivers of late Holocene relative sea-level changes in western Iceland*

14.30-14.50 P. Punwong, K.A. Selby, R. Marchant *Holocene sea level changes along the Tanzanian coast, East Africa*

14.50-15.10 D.E.Smith, S. Harrison, J.T.Jordan *Sea level rise and submarine mass failures on open continental margins*

15.10-15.40 Coffee

Session Chair: Professor Roland Gehrels

15.40 -16.00 M. Hijma, S. Yu, T. Törnqvist, Z. Shen, *Evolution of Louisiana's Chenier Plain: implications for the Mid/Late-Holocene highstand debate*

16.00-16.20 M.J. Tooley *All at sea in south-west Lancashire: a forty-five year critical retrospect of sea-level investigations*

16.20-16.40 G. Ruggieri, G. Spada *Sea-level change during the Roman period along the coast of Central Italy*

16.40 Discussion

Conference dinner

5th July

New methods to observe and reconstruct coastal change

Session chair: Dr Robyn Inglis

10.00-10.50 **Keynote: Professor Gerd Masselink** *The importance of field research and numerical modelling in coastal morphodynamic research: why 1+1 is more than 2*

10.50-11.10 W. R. Gehrels, W.P. Anderson Jr. *Holocene sea-level reconstructions from freshwater backbarrier peat systems*

11.10-11.30 M.D. Bateman, K.A. Selby, G. Swindles, J. Jones, C. Woulds, K. Penkman *Do dunes contain an archive of storm events?*

11.30-12.00 Coffee

Marine archaeology

Session chair: Dr Margot Saher

12.00-12.50 **Keynote: Professor Geoff Bailey** *Submerged Landscapes and Marine Geosciences: An Archaeological Perspective*

12.50-13.50 Lunch and poster viewing

13.50-14.10 A. Bicket, L. Tizzard *Palaeogeography and prehistory: investigating the current state of knowledge of submerged prehistory and palaeolandscapes in the British Isles.*

14.10-14.30 P. Murphy *The English Heritage Rapid Coastal Zone Assesssment surveys (RCZAS). Oral presentation.*

14.30- 14.50 E. Hill, C. Hunt *Exploitation of marine resources at the Haua Fteah, Libya, during OIS2 and OIS3*

14.50 – 15.10 R. Inglis, M. Meredith-Williams *Beyond the coastline - integrating submerged and dryland landscape archaeology in the Southern Red Sea*

15.10-15.30 Discussion and close

Nutrients and ecology of the coastal zone – how good is our science and is it sufficient for environmental understanding and management?

Keynote speaker: Professor Mike Elliott
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When managing nutrient pollution and eutrophication in estuaries and the coastal zone, inputs from the catchments are regarded as an *exogenic unmanaged pressure* in which the consequences have to be addressed even if there is no control locally over the causes of the problems. However, if as is the case nowadays the whole catchment is to be managed (as in River Basin Management) then this is regarded as an *endogenic managed pressure* whereby both the causes and consequences are to be tackled. Despite that, inputs of nutrients and their suite of undesirable symptoms, which constitute eutrophication, are influenced by climatic patterns and global systems such as the North Atlantic Oscillation as well as by land use and urban discharges and run-off. The NAO delivers nutrients into the northern European seas not only from rainfall patterns but also by ocean current transport thus making it more difficult to detect the influence of land-based diffuse and point-source discharges on the estuarine, coastal and marine areas. The role of the estuaries and coastal zone as both sources and sinks of nutrients is particularly important in attempting to understand this particular stressor. This presentation reviews the causes of nutrient pollution and its extent, the links to organic enrichment and the means of tackling eutrophication, the spatial and temporal nature of the problem, and the role of modelling and monitoring in marine management. As such, the discussion covers the potential influence of climate change and the way in which our use and misuse of nutrients affects the delivery of ecosystem services and hence the production of societal benefits dependent on an unpolluted environment. Finally, it looks at the science required by the prevailing governance and the environmental regulators and indicates how the adequacy (or inadequacy) of the science related to this particular environmental stressor has been mentioned in the UK High Court and the European Court of Justice.

Changing salinity and nutrient dynamics in the Limfjord, Jutland (Denmark) over long and short timescales

Jonathan P. Lewis[1], David B. Ryves[1], Peter Rasmussen[2], Karen Luise Knudsen[3], Kaj S. Petersen[2], Jesper Olsen[4], Thorbjørn Joest Andersen[5] and Kilen Project members
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[5]*Department of Geosciences and Natural Resource Management, Department of Geography and Geology, University of Copenhagen, Øster Voldgade 10, 1350 Copenhagen, Denmark.*
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Here we present proxy data (including sedimentary parameters, diatoms, molluscs, foraminifera, sedimentary pigments, C and O stable isotopes and plant macrofossils) from a sedimentary sequence collected from Kilen, a small fjord site in the Western Limfjord, Denmark, to assess how salinity and nutrient levels have changed over both long (last 7,500 years) and short timescales (last 150 years). We show that salinity (quantified using a diatom-based salinity model) and nutrient dynamics at this site are heavily driven by marine exposure, which in turn is driven by the complex interplay between climate, sea-level change, current velocity, rates of erosion/sedimentary accretion and in more recent times by human impact. During times when an open connection with the Limfjord existed (up until AD 1856), salinity was the dominant variable driving changes in floral and faunal communities, and several large scale shifts are evident over the last 7,500 years, including regular stratification up until ca. 4,400 BP.

However, building of a road and rail embankment in AD 1856 has almost isolated Kilen from the Limfjord (except for a narrow connection maintained in its SW corner) and completely changed salinity-nutrient dynamics within the system. Since AD 1856, brackish salinity and eutrophic conditions have prevailed within the basin and problems associated with low oxygen conditions have been common, prompting management strategies to be introduced (e.g. environmental monitoring and sluice improvement to increase water exchange). In addition to wholesale ecosystem

changes, isolation from the Limfjord has shifted dominance from salinity, to nutrient concentrations as the major driver of change in the diatom assemblages. A diatom-based quantitative total nitrogen reconstruction is presented for the last ~150 years using a transfer function based on a modern Baltic surface sediment training set. This model is evaluated against monitoring data collected for key variables between AD 1972-1987.

Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures

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In the next decades climate change will pose a significant stress to ecosystems and to the environment in addition to human health and economical impacts. Previsions point to increased CO_2 concentrations in the atmosphere, global temperature rise, increased rainfall or draughts, and further emissions from the increased transport- and energy-related demand, and others. Disruptions in the agriculture and food production sector worldwide are among the most important impacts. Predicted increases include 50% in cereal production by 2030 (1995 baseline) and 40% in population, 37% in fertilizer application and 7% of arable land. The pressure posed by these figures can be translated into increased nutrient, e.g. Nitrogen (N) and Phosphorus (P), runoff and export. The N loadings exported to marine coastal waters have a potential impact to marine eutrophication due to nutrient fertilization. Marine eutrophication processes include the excessive growth of phytoplankton biomass in response to increased availability of N in the photic zone of marine coastal waters. Eventually, the degradation of this organic matter (OM) results in dissolved oxygen (DO) consumption in bottom waters by bacterial respiration. Land-based human interventions largely determine the N loadings to marine coastal systems and are overrunning their natural capacity to absorb N.

Marine eutrophication is one of the impact categories in LCIA, which typically delivers Characterisation Factors (CF) to express the potential impacts of an emission from a product system (i.e. human intervention). A model was built to estimation endpoint CFs for marine eutrophication combining Fate Factors (FF) estimated for both airborne and waterborne N emissions based on modelling of river-N and marine-N losses, Exposure Factors (XF) to cover biological incorporation of N and degradation of OM in the photic zone, and DO consumption in the benthic habitat, and finally, Effect Factors (EF) by applying the statistical Distribution of Species Sensitivity (SSD) to hypoxia introducing species diversity loss as the ecosystem damage dimension. The product of the three factors, FF•XF•EF delivers the CF in (PAF•)[m^3•d/kg], to be applied to the inventoried amount of N [kg], at a suitable spatial differentiation to support a consistent

emission-impact model. Spatial differentiation is essential in addressing the geographical variation of the results and in increasing the discriminating power of the methodology and the relevance of the assessed impact. Marine eutrophication, as a non-global impact category, may therefore benefit from a spatial differentiation approach in the fate, exposure to possible receptors, and effects on these, to support the site-dependent impact model. The model provides CFs for the inventory flows of 214 country-to-LME (Large Marine Ecosystems) combinations, 143 countries, 11 regions/continents, and a global default level. Comparing the impact of any given year and country´s emission scenario would provide useful and relevant information to supply science and decision-making process.

What challenges remain in understanding past and future sea-level variability?

Keynote speaker: Dr Ivan Haigh
Ocean and Earth Science, National Oceanography Centre Southampton, University of Southampton, Waterfront Campus, European Way, Southampton, SO14 3ZH; email: i.d.haigh@soton.ac.uk

There is observational evidence that global mean sea levels are rising and there is concern that the rate of rise will accelerate, significantly threatening growing coastal communities. In the first part of this talk I will provide an overview of the significant progress that has been undertaken in recent years in describing and understanding global-mean sea-level rise. I will start by presenting results from direct measurements of sea level made by tide gauges over the last two centuries and altimetry data collected over the last two decades, outlining the advantages and disadvantages of both dataset and the recent progress made in reconstructed global trends by combining both datasets. I will then put these 'modern' observed changes in mean sea level in a historic context, by comparing the changes with variations in sea level inferred from in-direct measurements made from salt marshes and geological and archaeological data over the last several thousand years, last 500,000 thousand years and then over millions of years. Following this, I will review estimates of sea level rise projections for the coming century. In the second part of the talk I will focus on the challenges that remain in understanding past and future sea-level rise and variability, discussing the need to: (i) improve understanding of regional departures of sea level trends from the global-mean rates; (ii) provide probabilistic sea level projections; (iii) more accurately determine the full range of possible future sea level rise projections, in particular the low probability but large impact scenarios, such as H++; and (iv) detect a significant increase in the rate of sea level rise as early as possible to trigger the public and thus the political motivation for action, and to enable adequate adaption.

Evidence of past glacial activity and relative sea-level change from the submerged landscape of Belfast Lough

S. Louise Callard[1*], Antony J. Long[1], J. Andrew Cooper[2], Dan Belknap[3], Robin J. Edwards[4], Joe Kelley[3], David Long[5], Xavier Monteys[6], Ruth Plets[7], Rory Quinn[7]
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Differential isostatic depression during the last glaciation and the subsequent postglacial rebound has led to spatially complex relative sea-level (RSL) records from sites in the UK and Ireland. Glacial Isostatic Adjustment (GIA) models predict the extent of these land movements and forecast future change. The models are constrained by RSL observations, however these data are mainly derived from terrestrial and intertidal settings and there is a paucity of observation from altitudes of >10 m below present sea level. This means that there are few observations for the period immediately following ice retreat, when patterns of GIA were rapid.

We present initial results from ongoing investigations, carried out as part of a wider project “Late Glacial Sea Level Minima in the Western British Isles” that seeks to better constrain GIA models during the Late Glacial. We present preliminary results from one of our six sites, at Belfast Lough in Northern Ireland. This northern site experienced large ice load change during the last glacial, including several short-lived glacial readvances during deglaciation, the latest of which is thought to have occurred around 15-15.5 k cal a BP (the “East Antrim Re-advance”). This re-advance is contentious since it implies ice expanding rapidly from SW Scotland, a region previously thought to be ice free at this time. The modelled RSL curve during the Late Glacial predicts rapid sea-level fall at the start of deglaciation, culminating in two closely space sea-level lowstands separated by an intervening meltwater pulse. Existing RSL data suggest a RSL lowstand of -30 m at 13.5 k cal a BP. This is 15 m deeper than the RSL predicted by GIA models and highlights the discrepancies that exist between modelled and observed RSL record for this region. We use a combination of marine geophysics, vibro-coring and laboratory analyses to reconstruct Late Glacial RSL change in Belfast Lough . We identify a single transgressive surface that we trace to at least -20 m below current sea level, lower than the current predicted sea-level lowstands. Our results are preliminary, but we

expect that ongoing investigation and dating of this transgressive surface will enable a better understanding and prediction of the complex RSL and deglacial history of this site.

Drivers of late Holocene relative sea-level changes in western Iceland

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Iceland is exposed to prevailing westerly winds associated with the North Atlantic Oscillation (NAO). Its position on both the mid oceanic ridge and a hotspot means it has thin, flexible continental crust. Waxing and waning of the various Icelandic ice caps therefore leads to strong glacial isostatic adjustment (GIA). These factors complicate the sea-level evolution of Iceland, and thus hamper making reliable predictions. In this paper we explore the influences of wind climate and GIA on the late Holocene sea-level history of western Iceland.

We revisit Viðarhólmi salt marsh in Faxaflói Bay, the site of a 2000-year, foraminifera-based relative sea-level record (Gehrels et al. 2006). This record showed a steadily rising relative sea level, marked by a sharp acceleration starting in the first half of the 19th century. In this paper we improve the precision of the record over the last 600 years by using diatoms and testate amoebae as sea-level indicators and by adding many high-precision radiocarbon dates, and a date based on ash from the Katla 1721 eruption. We used Bacon (Blaauw and Christen, 2002) to construct an age model for the sequence.

The resulting sea-level reconstruction shows a ~66 cm overall sea-level rise since 1385 AD. This rise occurs mainly in three steps, centred on the periods 1500-1655, 1740-1860 and 1960-1995 AD. The maximum rate of sea-level rise occurs between 1960 and 1995 at ~4mm/yr.

We compare our improved record with advances and retreats of Icelandic glaciers, and with NAO reconstructions. Our reconstructions do not suggest GIA is the likely cause of the observed periods of rapid sea-level rise. A combination of basin-wide sea-level change and wind forcing described by NAO are the most likely drivers of late Holocene sea-level variability in western Iceland.

Holocene sea level changes along the Tanzanian coast, East Africa

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Mangroves, a group of tropical trees and shrubs, possess a specific vertical relationship with salinity. Pollen preserved in sediment cores may be used as a proxy to investigate past sea level changes. This research investigates the potential of mangroves along the Tanzanian coast to reconstruct Holocene sea level change. A contemporary vegetation survey of mangrove zonations along altitudinal transects taken from sea to land was undertaken to establish the different major vegetation associations with respect to mean sea level. A Holocene sea level curve for the Tanzania has been developed from three sites; Rufiji Delta, Makoba (Zanzibar) and Unguja (Zanzibar). An early-mid to mid Holocene sea level rise was recorded from ~ 8000 cal yr B.P. prior to 4600 cal yr B.P. with two potential mid Holocene highstands at ~ 5900 cal yr B.P. and ~ 4700 cal yr B.P. After around 4600 to 4400 cal yr B.P., a lower sea level was recorded followed by a further sea level rise between 4400 and 2000 cal yr B.P. Sea level fluctuations occurred in the last thousand years with a potential highstand at ~ 530 cal yr B.P. before falling to a lower than present level at ~140 cal yr B.P. The most recent sea level rise was recorded during the last centuries.

Sea level rise and submarine mass failures on open continental margins

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Open continental margins are amongst the most dynamic regions of the ocean floor, and many mass failures (sometimes called submarine slides or submarine landslides) in these areas are some of the largest features on the surface of the earth. The rôle of sea level change in the origins of these features is as yet imperfectly understood, but a number of studies undertaken in recent years indicate that sea level change, especially sea level rise, may be of greater importance than previously realised. This paper will maintain that sea level rise may cause mass failures by causing seismic activity on the continental margin and at the same time increasing fluid overpressure within the sediments. As evidence of this, the ca. 8100 BP quasi-simultaneous Holocene Storegga Slide, off South West Norway, is examined, and is believed to have been caused by the effects of the early Holocene sea level rise, accentuated by meltwater flux from discharges of Lake Agassiz-Ojibway in North America. Relative sea level rise increased water loading on the Norwegian continental margin, causing seismic activity and increasing overpressure in the sediments, triggering the largest individual Holocene submarine mass failure yet recognised. It is argued that an improved understanding of the origins of submarine mass failures will benefit from detailed empirical knowledge of the spatial and temporal patterns of rates of sea level rise.

Evolution of Louisiana's Chenier Plain: implications for the Mid/Late-Holocene highstand debate

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In the last decade or so there has been a heated debate about whether or not sea level reached a highstand of +2 m during the Mid/Late-Holocene in the northern Gulf of Mexico. Beach ridges above the present-day sea level and dated to that time were used in favour of the highstand hypothesis, while in contrast high-resolution basal-peat records showed a continuous sea-level rise throughout the mid/Late-Holocene.

One of the sites that has been used to advocate a sea-level highstand is the Louisiana Chenier Plain that lies west of the Mississippi Delta. It consists of an alternation of sand ridges (cheniers) and marshes with the oldest ridge being the most landward. Radiocarbon dates from the fifties indicate that the Chenier Plain formed in the past 3,000 years and hence since then net progradation has occurred. This has been used as a major argument that 3,000 years ago there was a sea-level highstand and the subsequent sea-level fall resulted in the Chenier Plain progradation.

To settle the debate we conducted extensive fieldwork to obtain data on both the sea-level history and the evolution of the Chenier Plain. Basal peats were collected and AMS radiocarbon dated. Boreholes were drilled to understand the build-up of the Chenier Plain and to take sandy samples from the cheniers for OSL dating.

The sea-level data show a steady relative sea-level rise from about -5 m at 6500 BP to about -1.5 m at 3000 BP (Yu et al., 2012). The sea-level trend fits perfectly with sea-level data from just east of the Chenier Plain that start at about -1 m at 1500 BP. Hence there is no indication for a sea-level highstand in the Chenier Plain sea-level record. The OSL data show that the most landward chenier formed at 2900 a and the more seaward cheniers are progressively younger (Hijma et al., in prep). Currently active cheniers along the coast of Louisiana show that the base of a chenier lies close or just above present-day sea-level. The base of the 2900 a chenier lies at -1 to -1.5 m, very close to contemporaneous sea level. The base of the younger cheniers all lie higher then the base of the oldest chenier, in agreement with a steadily rising sea level during the past 3000 year.

The new data invalidate the highstand hypothesis and show that sea level along the northern shores of the Gulf of Mexico has been steadily rising throughout the mid/Late-Holocene.

Yu, S., Törnqvist, T.E. and Hu, P., 2012. Quantifying Holocene lithospheric subsidence rates underneath the Mississippi Delta. *Earth and Planetary Science Letters 331-332: 21-30.*

Hijma, M.P., Shen, Z., Törnqvist, T.E., and Mauz, B. New geological data for Louisiana's middle-late Holocene Chenier and Mississippi Delta Plain evolution: are they interlinked? *In prep.*

All at Sea in south-west Lancashire: a forty-five year critical retrospect of sea-level investigations

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The publication in May 2013 of 'The Wetlands of South West Lancashire,' in which all the data available on sea-level changes in this area have been marshalled, provides the opportunity for a critical review of sea-level investigations here over the past forty-five years or so.

1961 was a critical year for sea-level studies, for in that year were published the seminal papers by Fairbridge and by Jelgersma, the former arguing for a markedly oscillating sea level during the Holocene and the latter for a smoothly rising sea level. The influence of the latter resulted in the first sea-level curve for south-west Lancashire (Tooley 1971) whereas three years later Fairbridge's influence was apparent (Tooley 1974). The great value of Fairbridge's oscillating sea-level curve was that correlations were possible with changes in climate and these were not possible with Jelgersma's asymptotic curve, and indeed are not possible with the curves constructed by Shennan and Horton (2002) focused as they are on constraining models of glacial isostatic adjustment.

The new data on sea-level changes from south-west Lancashire have been conflated with data collected in the 1960s and 1970s and reinforce the conclusion that the restoration of sea-level followed a markedly oscillating course which can be correlated with local, regional and global events (for example, ocean volume changes. Tooley *et al.* 2000)

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Sea-level change during the Roman period along the coast of Central Italy

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The accuracy of glacio-isostatic adjustment (GIA) model predictions depends critically on assumptions being made for the rheology of the mantle and the history of ice melting. Here we focus on these two model parameters by employing viscosity profiles in the range of 0.1-0.5x10^{21} Pa s for upper mantle and 10^{21} 10^{22} Pa s for lower mantle and several late-Pleistocene ice-sheets chronologies. Model outputs were validated by archaeological relative sea-level (RSL) observations collected on the coast of central Italy which has been re-visited as part of the European COST Action ES0701. The re-assessment of the RSL data indicate a ~0.5 m RSL rise since 0 AD which agrees with the classical literature about this topic, rather than ~1.35 m, as recently proposed. Best model fit to this data was obtained with laterally uniform upper of 0.5 x10^{21} Pa s and lower mantle viscosity of 2.7 x10^{21} Pa s for ICE-5G model (Peltier, 2004) and 10^{22} Pa s for KL05 model (Lambeck et al., 1998). As a result of this sensitivity study, we can say that the RSL curves for this region depart from global eustasy mainly because of the effects of melt-water loading, responsible for a widespread subsidence reaching its largest amplitude in the centre of the Tyrrhenian Sea basin.

The importance of field research and numerical modelling in coastal morphodynamic research: why 1+1 is more than 2

Keynote speaker: Professor Gerd Masselink
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Most commonly, field research of coastal processes (including wave/current hydrodynamics, sediment transport and morphological change) is carried out by geographers, physical sedimentologists and oceanographers, whereas numerical modelling of coastal processes belongs to the realm of coastal engineers. Both methodologies are valid, but both also have clear constraints. If properly and comprehensively carried out, field measurements yield useful information of the measured phenomenon, but only at the field site and under the conditions monitored. Field data and understanding gained is therefore strongly site-specific and constraint by the conditions under which the measurements were made. Numerical models, on the other hand, are generic and can be used for a wide range of conditions; they can also be used for scenario testing and making predictions. However, even if properly calibrated and validated, numerical models remain representations of reality and this should always be born in mind when interpreting model outputs.

In this presentation, two case studies are used to argue the benefits of a two-pronged approach, involving both field research and numerical modelling, to investigate coastal processes. The two projects used to illustrate the added value of such combined approach are the NERC-funded DRIBS project (Dynamics of Rip currents and Implications for Beach Safety) and the EPSRC- funded NUPSIG project (New Understanding and Prediction of Storm Impacts on Gravel beaches). Both projects also have a strong applied aspect and it is here that such combined approach really pays dividends.

Holocene sea-level reconstructions from freshwater backbarrier peat systems

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Reconstructions of Holocene relative sea-level change are usually presented in time-altitude graphs in which the data that are plotted are known as sea-level index points. There are three main types of sea-level index points. The most reliable index points, immune to compaction, are derived from peat or coastal sediments formed at the base of the Holocene sedimentary section, directly overlying a hard substrate, usually sand or rock. Of lesser quality are intercalated index points collected from within thick Holocene clay and peat sequences. These may have been displaced downwards by the weight of overlying sediments. A third category of sea-level index points are those that are 'limiting'. These are derived from freshwater samples (such as fen peat) that have been formed above sea level, but it is unknown how far above sea level. Limiting index points can also be marine samples that have formed, by an unknown distance, below a chosen tidal level.

In this paper we present new sea-level index points derived from freshwater coastal peats at Hallsands in southwest England. We show that in gravel-peat barrier systems these index points can be highly accurate because the water table in the backbarrier marsh is directly controlled by tide levels. We demonstrate that on longer time scales vertical peat growth in these systems is controlled by sea-level rise. Data scatter in existing sea-level reconstructions from southwest England is mostly due to morpho-dynamical and sedimentary processes such as channel meandering and bank erosion that operate in open backbarrier systems. Unlike sea-level index points derived from salt-marsh sediments, points from closed barrier systems are not affected by such processes. In this paper we add five new sea-level index points to the sea-level reconstruction for southwest England and argue that these new data are the most precise sea-level index points yet obtained. In addition, we calculate with a numerical model the barrier permeability that is required for peat growth to be directly controlled by tidal movements, thus facilitating the application of our methods in other backbarrier systems.

Do dunes contain an archive of storm events?

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A White Rose funded project has been investigating whether salt marshes behind dunes, and dunes themselves, have the potential to act as an archive of storm events. Work has focussed on the extensive dune and salt marshes which occur at Spurn Point on the East Yorkshire Coastline. Spurn is a dynamic spit formed by southerly longshore drift of sediment form the East Yorkshire coastline into the Humber estuary. Initial work had suggested that the spit in its most current form was at least 200 years old at the tip and that sediment half-way along the spit was at least 500 years old. Vegetated dunes form on both the north-sea coast side of the spit and on the estuary side of the spit. The latter are dependent on sandy sediment either being transported around the end of the spit and northward, or from sediment over-washed during storm events. New investigations using portable luminescence have shown that the dunes either side of the spit have a different sedimentary history and both are far more dynamic that first thought, with extensive accumulations of sand over the last 60 years. Preliminary results suggest phases of dune accretion may be initiated by particular extreme storm events causing sediment to become available for subsequent dune building rather than dune directly accreting as a result of storm events.

Submerged Landscapes and Marine Geosciences: An Archaeological Perspective

Keynote speaker: Professor Geoff Bailey
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The past decade has witnessed a rapidly growing interest in the prehistoric archaeology of the continental shelf, and a variety of new initiatives, many involving collaboration between across many archaeological and marine-science disciplines. In this presentation I will discuss the new work and ideas that are now informing this research initiative. The primary driver for these developments is the growing realisation in the archaeological community that for most of human existence on this planet sea levels have been substantially lower than present, and that sea level change has been a near-constant feature of human existence. One implication is that many of the formative developments in human evolution, including Pleistocene population dispersal, the early development of marine fishing and seafaring, and the early development and dispersal of agricultural communities, took place when sea levels were lower than present. Given the general attractions of coastal regions and the tendency of populations to concentrate there, it follows that some of the most important evidence may be missing and only accessible through underwater exploration. This poses enormous technical challenges, but also great opportunities – to transform our understanding of world prehistory, to gain new and more precisely dated palaoeshoreline data that can feed into improved models of sea level change, and to understand how past populations responded to coastal and sea level change, which may offer insights into the social and technological challenges of future sea-level rise. Collaboration with industrial companies working offshore, and with government agencies responsible for managing the underwater cultural heritage, is also opening up new funding and research opportunities.

Palaeogeography and prehistory: investigating the current state of knowledge of submerged prehistory and palaeolandscapes in the British Isles.

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Significant progress has been made on the investigation of submerged prehistory in the British Isles over the last 15 years (Wessex Archaeology 2013). Substantial knowledge of the distribution and nature of preserved palaeolandscapes dating to beyond the last 1 million years have been identified in UK waters. *In situ* archaeological remains deriving from these inundated continental shelves are currently known to around 250,000 years off Great Yarmouth, East Anglia. Here, a Middle Palaeolithic assemblage of handaxes and Levallois flakes and cores has been recovered from the seabed and studied in detail (Tizzard, Bicket, De Loecker, In Review; Tizzard, Bicket, Benjamin, In Review) – the only such site in the world to date.

More recent archaeological material is well-represented with an established focus on Mesolithic palaeolandscapes, often referred to as 'Doggerland'. A diverse array of prehistoric material has been recovered from the seabed over the last century or so including bone and stone tools from the Northern Isles to southern England; extinct fauna; and, widely distributed reports of submerged forests and other remnants of relict landscapes from around the British Isles. The recovery of artefacts has mainly been of out-of-context or poorly-located material and 'sites' are few and far between. New data from the Outer Hebrides has provided an important palaeogeographic context for investigating maritime transport, marine resources and Mesolithic activity at the edge of the world in the early Holocene. This has permitted a detailed assessment on future areas of prospection for submerged sites and palaeolandscapes.

Mainly through collaboration with industry, in particular the marine aggregates industry, a considerable knowledge-base has been developed (Wessex Archaeology 2013). Investigating submerged prehistory provides unique opportunities to understand the breadth of the archaeological record, wherever it may be preserved today. An overview of the current state of knowledge will be presented with the emerging picture from across the UK, including case studies

from recent palaeogeography reconstructions from Area 240 and the Outer Hebrides.

Tizzard, L., Bicket, A.R., De Loecker, D., (In review). “Seabed Prehistory: Investigating the palaeogeography and Early Middle Palaeolithic archaeology in the southern North Sea” Wessex Archaeology & English Heritage Monograph.

Tizzard, L., Bicket, A.R., De Loecker, D., Benjamin, J., (In review) “A Middle Palaeolithic Site in the southern North Sea: Investigating the archaeology and palaeogeography of Area 240” *Journal of Quaternary Science*.

Wessex Archaeology, (2013). “Audit Of Current State Of Knowledge Of Submerged Palaeolandscapes And Sites”, English Heritage Report 6231.

The English Heritage Rapid Coastal Zone Assesssment surveys (RCZAS)

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Until the later 20th century coastal management was focused on defence. More recently, the emphasis has shifted towards risk management, long-term sustainability and adaptation, in the light of current climate change projections (Defra 2010, 2012; McInnes 2008). English Heritage noted early on that the coastal historic environment was under-investigated and records in the National Record of the Historic Environment (NRHE) did not provide an adequate evidence base for responding to new policies, Shoreline Management Plans, strategies and individual Flood and Coastal Erosion Management schemes. Consequently, the national RCZAS programme was initiated. RCZAS comprise:

Phase 1 (Desk-Based Assessment), which draws on data from aerial photographs, lidar, historic maps and charts, the local authority Historic Environment Records (HERs), the NRHE and other sources; and

Phase 2 (Field Assessment), which comprises a rapid walk-over survey, designed to verify records from Phase 1, locate and characterise site types not visible from the air, to assess significance and vulnerability and advise on possible designation.

No formal Phase 3 was defined, but in some cases additional work, (especially scientific dating and more detailed survey of specific locations), has been necessary to characterise sites fully. Reports are available on: http://www.english-heritage.org.uk/professional/advice/advice-by-topic/marine-planning/shoreline-management-plans/rczas-reports/

Surveys are continung as part of the National Heritage Protection Plan, although survey of some parts of the country will not be completed during the present NHPP round, up to 2014: specifically the South East and South West (Phase 2).

Defra 2010 *Adapting to Coastal Change: a Policy Framework*. London: Defra

Defra 2012 *UK Climate Change Risk Assessment 2012: Evidence Report.* (Defra Project Code **GA02024**). Defra, Welsh Government, DOE Northern Ireland, The Scottish Government. http://www.defra.gov.uk/environment/climate/government/

McInnes, R 2008 Coastal Risk Management – A Non-Technical Guide. Ventnor: SCOPAC

Exploitation of marine resources at the Haua Fteah, Libya, during OIS2 and OIS3

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Analysis of molluscs and high-resolution radiocarbon dating of shell from the new excavation of the Haua Fteah, NE Libya, suggests a series of short phases of human activity. The record of human activity in the cave appears fairly continuous and was described as such by McBurney (1967), but this is most likely an artefact of sedimentary processes, which caused localised recycling of archaeological material. These activity phases gave rise to the 'Mousterian', 'Dabban' and 'Oranian' lithic industries delineated by McBurney (1967). Activity phases are largely coincident with Greenland Interstadials during OIS3. There are two further phases of activity during OIS2. Coastal molluscs were exploited during these phases of activity as part of a broad-spectrum strategy of food procurement. Marine shell was used for ornament, but some appears to have been derived from Quaternary deposits, rather than from contemporary shorelines.

Beyond the coastline - integrating submerged and dryland landscape archaeology in the Southern Red Sea

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Reconstructing submerged landscapes is essential for understanding archaeology found on land that relates to periods of lower sea level. Whilst this is challenging, an interdisciplinary approach provides the tools to begin understanding environments and landscapes to which past populations would have had access. Climate and environmental reconstruction are also important aspects, since some landscapes may have been more challenging or attractive in the past. Whilst finding submerged prehistoric archaeological sites is unlikely, it should be possible to determine areas that would have been more attractive to past populations.

The southern Red Sea is one such area where changing sea levels have had a major impact upon prehistoric coastal populations. It has a broad continental shelf that is less than 100m deep and therefore would have been exposed during low stands of sea level. During these periods the Hanish Sill between Africa and Arabia would have been much reduced, making crossing by prehistoric populations more feasible, possibly even the first migrants out of Africa. One of the questions that needs to be addressed here is whether these populations were assisted by an ability to exploit coastal resources? In later prehistory there is extensive evidence of specialised economies based on the exploitation of coastal resources, and others that exploited coastal resources of as part of a more varied subsistence pattern. This area is therefore well suited as a laboratory to examine long-term interactions of sea level change and human occupation, including the extent to which these populations were coastally adapted.

This paper presents the approaches taken by the DISPERSE Project to examine the changing coastlines and prehistoric landscapes of the Red Sea. We have discovered over 3000 mid-Holocene shell mounds on land that represent a specialised coastal adaptation, and can provide a high-resolution record of the complex interactions between populations and changing climate and sea level in the mid to late Holocene. Palaeolithic evidence is currently more sparse; however we have identified uplifted marine terraces on the present-day coastline (Al Birk) and potential use of these early coastlines. On the submerged landscape we have started to identify elements of the submerged land surfasce, including river

channels and inundated deltas. Broad scale work using bathymetry, sonar and seismic survey is currently being undertaken to build on these initial findings. This data should allow a broader scale reconstruction of environmental and landscape change, which can be complemented with climatic data. These reconstructions can then be used to identify areas attractive for human populations, as well as bench marking sea level change in the area. Areas that look particularly promising will be targeted for deep diving at a later stage.

The result will be an integrated reconstruction of the whole landscape, submerged and exposed, examining impacts of changing sea levels both on landscapes and on the populations that inhabited them.

Reconstructing historical sea-level trends for the Croatian coast of the Adriatic using saltmarsh foraminifera

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Late Holocene sea-level records from the Mediterranean are heavily reliant on geomorphological and archaeological data. However, these indicators do not overlap in time with the more recent tide gauge record and their relationship with a precise former tidal level (indicative meaning) is often ambiguous. Here we present a foraminifera-based transfer function from saltmarsh sediments from the Croatian coast of the Adriatic to reconstruct former sea levels spanning the past two centuries. This is a first for the Mediterranean region.

In the Mediterranean Sea, the record of sea-level change is complex due to an interplay between oceanic, climatological, glacio- and hydro-isostatic factors, and tectonic activity. The long-term tide gauges in the Mediterranean show sea-level trends for the 20th century in the range of 1.1 – 1.3mm/yr. However, sea level in this region is not homogeneous in space or time. Before 1960, sea-level trends were of equivalent magnitude to global estimates for mean sea level rise at 1.2 and 1.5mm/yr, yet between 1960 and the early 1990s tide-gauge measurements reveal sea level falling at a rate of -1.3mm/yr. Satellite altimetry data since 1993, however, show a substantial rise in sea-level throughout the majority of the region at rates ranging between 15 – 25mm/yr.

Our study utilizes a modern foraminiferal training set containing 60+ surface samples from micro-tidal (<0.4m) saltmarsh sites along the central Croatian coastline. Multivariate analyses have identified elevation dependent faunal zones confirming the suitability of the training set for palaeo-sea-level reconstruction. The core chronology, based on Pb^{210}, C^{14} and geochemical markers shows the sediment record dates from around AD1800. These data demonstrate that historical sea levels can be reconstructed using a transfer function approach which can be compared with direct observations from nearby tide gauges at Trieste and Split.

Environmental Geochemistry Of Sediments From Khai River Estuary Of Nha Trang Bay, South China Sea

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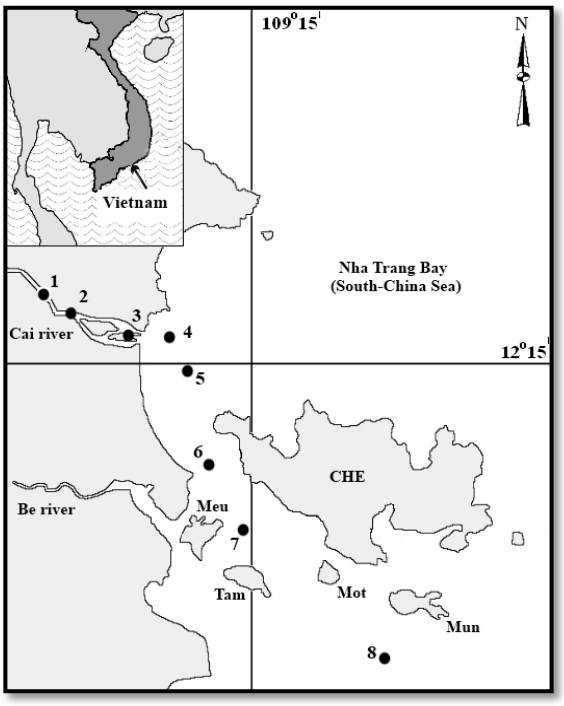
The Khai River and the Nha Trang Bay form one of the major estuarine systems in the South China Sea that is inhabited by unique biota. This area now experiences a significant anthropogenic load from the local people activities and, especially, from the quickly growing tourist industry.
The present study focused on the environmental assessment of Khai River - Nha Trang Bay estuarine system that required complex geochemical examination of sediments. Therefore, Al, Fe, Ti, Mg, Ca, P, S, Na, K, Mn, Cr, Ni, Cd, V, Zn, Cu, Pb, Sb, Bi, Sn, Ag, Li, Co, As, Zr and Mo were first determined in surface sediment samples from the Nha Trang Bay by ICP-MS (X-7 Thermo Scientific). For Hg determination samples were pyrolyzed (RA-915+). TOC and TIC were determined on Shimadzu analyzer TOC Vcph.
Sediments that were studied are comprised mostly of aleurite silts and fine silts, the mean grain size generally decreased from the river to the bay.
Sedimentary organic content (TOC) showed relatively low variability in sediments studied ranging from 0,5 to 1,95% (mean 0,95%). The found mean TOC value was within the range of subcontinental sedimentary rocks (0,56%), submarine continental margin of the Pacific ocean (1,05%), and world riverbed sediments (1,4 %).
According to the sediment quality guidelines and reference background values data on the shale, pelagic clays, riverbed sediments and rural and industrial Vietnamese soils most of macro- and microelement contents that were studied were below the threshold levels, while the content of Cu, Pb, Ni and, especially Ag exceeded significantly the hazardous levels in the most of the samples.



Aluminum normalization indicated some specific features in distribution of elements along the salinity gradient. Thus, Ca, Ba and Sr are largely dependent on carbonates (TIC) content. Sedimentary P, Al, Fe, Mn, Ti, Na, K, Li, Co, Cs, Zn and V are most likely controlled by the accumulation of their fine grained aluminosilicate host minerals. S, As, Sn, Bi, U, Cd and Mo are scavenged by and/or co-precipitated with the dissolved and particulate materials of the river discharge and further deposited within the river – sea water mixing zone.

The distribution of Ni, Cr, Zr, Cu, Pb, Sb, Hg and, especially, Ag was characterized by anomalous high concentrations in the urban area of river-sea transect. This might be due to the point anthropogenic pollution from local human activities, i.e., fishing, shipping, fueling, waste and sewage sludge outflow, and, especially, from the construction of new touristic facilities in the Nha Trang Bay.

The anthropogenic and/or environmental sources of Ag in the region need special study.

The effects of storminess on coastal ecosystem services and wellbeing

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Coastal ecosystems are subject to multiple use pressures and are therefore some of the most threatened natural systems on the planet. Their position at the land-sea interface provides connectivity across these systems leading to linked provision of services, but also makes them subject to squeeze from both sides. Saltmarshes and sand dunes are two such ecosystems that provide a range of services from coastal protection and carbon sequestration, to tourism, recreation and education. Important psychological services are also likely to be provided by coastal environments, although these have received far less attention. Critically, these ecosystems are threatened by climate change impacts, notably projected changes in the frequency and magnitude of storm events.

This research will investigate how coastal sand dune and saltmarsh environments have evolved and developed in the past, particularly in the context of storm activity. A novel, interdisciplinary approach, combining analysis of borehole sediments to reconstruct past environmental conditions, with contemporary environmental psychological research, will enable an integrated assessment of the value of these coastal ecosystems.

Initial fieldwork has identified potential storm records within the sediment cores and preliminary particle size and geochemical analyses appear to show correlations with proposed storm horizons.

Late Holocene sea-level change and saline intrusion, Humber Estuary, UK

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Changes in sea-level are a key concern around the globe due to both the direct and indirect effects on coastal regions and resources. For the Yorkshire region this has resulted in particular concerns over the preservation of potable and plentiful water supplies. Groundwater is abstracted as a source of potable water from the chalk aquifer in close proximity to the Humber Estuary. There is a complex relationship within, and between, groundwater and estuarine coastal processes, and the risk of possible intrusions of saline water into the groundwater source needs to be investigated.

This project aims to establish a high resolution recent (last ~1000 years) sea-level record for the Humber Estuary through litho- and bio-stratigraphical analyses. Microfossils, primarily diatoms, will be used as proxy data to reconstruct former sea-levels. This will assist in understanding the Holocene evolution of the estuary, the implications of saline intrusion into the chalk aquifer, and consequences of possible future changes. The data can be used in conjunction with groundwater models to inform the decisions, policies and management strategies of the local water authority to safeguard future water supplies for the region.